

Language Switching and Language Representation in Spanish–English Bilinguals: An fMRI Study¹

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The current experiment was designed to investigate the nature of cognitive control in within- and between-language switching in bilingual participants. To examine the neural substrate of language switching we used functional magnetic resonance imaging (fMRI) as subjects named pictures in one language only or switched between languages. Participants were also asked to name (only in English) a separate set of pictures as either the actions or the objects depicted or to switch between these two types of responses on each subsequent picture. Picture naming compared to rest revealed activation in the dorsolateral prefrontal cortex, which extended down into Broca's area in the left hemisphere. There were no differences in the activation pattern for each language. English and Spanish both activated overlapping areas of the brain. Similarly, there was no difference in activation for naming actions or objects in English. However, there was increased intensity of activation in the dorsolateral prefrontal cortex for switching between languages relative to no-switching, an effect which was not observed for naming of actions or objects in English. We suggest that the dorsolateral prefrontal cortex serves to attenuate interference that results from having to actively enhance and suppress two languages in alternation. These results are consistent with the view that switching between languages involves increased general executive processing. Finally, our results are consistent with the view that different

languages are represented in overlapping areas of the brain in early bilinguals. © 2001 Academic Press

INTRODUCTION

How are multiple languages represented in the brain? Evidence from the aphasia literature dating back 100 years has revealed cases of selective impairment of one language (Paradis, 1995). These cases have led some to suggest that each language is represented in separate parts of the brain (Gomez-Tortosa *et al.*, 1995). Alternatively, it has been argued that lesions could result in a reduction of processing resources which differentially affects each language (Paradis, 1995, 1996).

Evidence in favor of a separate storage hypothesis in bilinguals has received support from studies using a variety of methodologies. For example, Ojemann and colleagues used direct cortical stimulation on patients who were candidates for neurosurgery. Bilingual patients were found to have areas where stimulation could interrupt naming in a first language, a second language, or both (Ojemann and Whitaker, 1978), thus lending support to the view that each language is processed by partially nonoverlapping areas.

More recently, researchers have turned to neuroimaging techniques to investigate the neural bases of bilingualism. Klein *et al.* (1994), using positron emission tomography (PET), found that naming pictures in a second language vs naming pictures in a first language resulted in activation in the putamen, a subcortical area that has been associated with phonological processing (D'Esposito and Alexander, 1995; Pickett *et al.*, 1998; Rosen *et al.*, 2000). Other studies have found that bilinguals show activity in left frontal areas of the brain for semantic and phonological analyses of words in both languages (Klein *et al.*, 1995; Wagner *et al.*, 1996). Similarly, Kim *et al.* (1997), using functional magnetic resonance imaging (fMRI), found overlapping areas of activation for each language in early learners of a second language in both Broca's and Wernicke's

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area in the left hemisphere when participants covertly recounted what they did the day before. For late learners, however, they found distinct foci of activation in Broca's area but not Wernicke's area. Kim *et al.* (1997) suggest that these results are consistent with the view that languages are represented in non-overlapping areas of the brain but only for late second language learners.

Other studies have found some evidence that languages may be represented in different areas. For example, Perani *et al.* (1996) asked participants to listen to passages in one of two languages. Results revealed that a second language showed different areas of activation relative to a first language in the left hemisphere. However, in a second study, Perani *et al.* (1998) found no differences between early and late bilinguals in the areas that were activated for each language for early and late bilinguals when fluency was controlled. Based on these two studies it appears that differential levels of fluency, rather than age of acquisition lead to the observation of different areas of activation for each language. These findings suggest that bilinguals who attain a high degree of fluency in a second language show very little difference in the areas of activation.

The finding that the two language systems of bilingual speakers utilize similar neural networks when processing different languages brings up another interesting point. Namely, how is it that bilinguals keep information from one language from constantly interfering with processing of the other language? The potential for interference is (at least in theory) massive, particularly in view of the overlap in neural tissue. To account for the lack of interference one could postulate the existence of a language switch, a separate brain region dedicated to controlling access to each language (Penfield and Roberts, 1959).

The search for a language switch has proceeded at both behavioral and neuroanatomical levels. At the behavioral level, there is mixed evidence for effects of language switching on performance in healthy young adult bilinguals. Some have found no evidence of language switching effects (Dalrymple-Alford and Aamiry, 1969; Kolers, 1966), while others have found significant effects of language switching particularly in terms of processing speed (MacNamara *et al.*, 1968; MacNamara and Kushnir, 1971; Soares and Grosjean, 1984). Furthermore, studies have found processing costs when switching between naming numerals in each language (Meuter and Allport, 1999) and when switching between lexical decisions in each language (von Studnitz and Green, 1997) relative to processing of each task in only one language. Finally, Green suggests that language switching costs involve competition between language task schemas which are responsible for the enhancement of the correct language and suppression of the incorrect language (for further discussion see Green, 1998a, 1998b).

In the past, findings based on autopsy of bilingual aphasics suggest that there may be areas of the brain that are involved in language selection. For example, Potzl (1983) identified a case of a patient who after a stroke had comprehension in two languages but could only speak one. In a second patient, he observed that the person mixed languages during speech even with monolingual speakers. Both patients had lesions in the left supramarginal gyrus, a finding which was confirmed by other researchers (Herschmann and Potzl, 1983; Kauders, 1983). However, others reported cases of patients with lesions in the left hemisphere including the supramarginal gyrus area, the posterior part of the sylvian fissure and adjoining areas of the parietal lobe in which there was no switching difficulty (Gloning and Gloning, 1983; Minkowski, 1983; Stengel and Zelmanowicz, 1933). One of the cases presented by Stengel and Zelmanowicz is of particular interest given that it was one of the few cases in which mixing of languages appeared both in spontaneous conversation and in picture naming for a person with a motor aphasia which was thought to be due to a left frontal lesion. Given these findings the precise locus of the area(s) involved in language switching is still an open question.

Hernandez *et al.* (2000) set out to investigate the brain activation associated with naming pictures in each language and in switching between languages, using fMRI. To accomplish this a group of six early Spanish-English bilinguals were told to name a picture in the same language as a cue. The cue, the word "say" in English and the word "diga" (i.e., "say" in Spanish) instructed the subject about the language of response. Two basic conditions were compared. In the blocked condition, participants were presented with cues in only one language (either Spanish or English). In the mixed condition, the cue alternated from English to Spanish on successive pictures. Participants would name one picture in English followed by the next in Spanish, etc. Because the pattern of alternation was predictable any difference between the blocked and mixed conditions should be due to task switching and not monitoring of what the task or the cue was (as would be needed if the switching pattern was unpredictable).

The results from this fMRI study revealed no differences between the two languages in the left and right hemisphere regions of interest which included the dorsolateral prefrontal cortex (area 46 and 9), the supramarginal gyrus (area 40), the inferior frontal gyrus (areas 44 and 45), and the superior temporal gyrus (area 22). However, there was significantly greater activation (in both signal intensity and spatial extent) in the dorsolateral prefrontal cortex (areas 46 and 9) in the mixed-language relative to the single language condition. These results suggest that the dorsolateral prefrontal cortex is involved in language switching during

picture naming. The dorsolateral prefrontal cortex has also been found to be active in tasks which require increased executive function (D'Esposito *et al.*, 1995) and in nonverbal task switching (Meyer *et al.*, 1997). This suggests that it is a general executive function and not a language specific process.

Price *et al.* (1999) also investigated the nature of controlled processing in bilinguals by using both translation and language switching. They predicted that switching, translation, or both should lead to activation in the dorsolateral prefrontal cortex. Translation revealed increased activation in the anterior insula, the cerebellum, and the supplementary motor area, regions that are associated with articulation. Switching input languages, however, revealed increased activation in Broca's area on the left and the supramarginal gyrus bilaterally, areas that are posited to be involved with phonological recoding. This finding provides an interesting parallel to the aphasia literature reviewed above. However, neither switching nor translation resulted in increased activation in the dorsolateral prefrontal cortex or the anterior cingulate gyrus, suggesting that executive function is not involved in all types of switching tasks.

The fact that not all switching tasks show the same amount of executive function brings up another interesting point. Can we identify similar types of activation when comparing within-language switching tasks with between-language switching tasks? To address this issue the current study was designed to explore these two types of language switching by using a bilingual between-language switching condition as well as monolingual within-language switching condition. In the between-language switching condition, participants were asked to name pictures of objects in English, Spanish, or to alternate between languages on successive pictures. In the within-language switching condition, participants were asked to name pictures as either the actions depicted, the objects receiving the action, or to alternate between these two types of responses on successive pictures. Based on previous studies (Hernandez *et al.*, 2000), we predicted that switching between languages would result in increased activation in the dorsolateral prefrontal cortex. It remains to be seen whether increased activation in the dorsolateral prefrontal cortex is also observed when switching within-languages.

The current experiment also allowed us to look at neural representation of multiple languages as well as the neural correlates of naming distinct lexical categories. As we used subjects who were relatively balanced across languages, we hypothesized very few, if any, differences in the patterns of activation observed for each language when subjects named objects in only one language. The predictions regarding potential differences in the patterns of activation for the naming of actions and objects is less straightforward. On the one

hand, evidence from the neuropsychological literature suggests that areas in the premotor cortex are responsible for the processing of verbs, whereas areas in the temporal lobe are responsible for the processing of nouns (Damasio and Tranel, 1993; Daniele *et al.*, 1994). On the other hand, more recent studies using neuroimaging techniques have yielded mixed results with regard to the areas that may be uniquely involved in processing one lexical class vs. the other (Chao *et al.*, 1999; Warburton *et al.*, 1996). Hence, this study may help in further identifying areas that are involved in action and object naming.

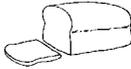
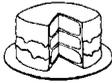
METHOD

Six participants (four female and two male) from the Santa Barbara and Los Angeles communities with a mean age of 21.7 (SD = 0.82, range 21 to 23) participated in the current experiment. All six were Spanish-English bilinguals who learned both languages before the age of five and were currently enrolled in or had completed college. None had any past medical history or had used medication. Participants scored significantly higher on the Boston Naming Test in English (50.4) than in Spanish (33) ($F = 6.00$, $P < 0.04$), indicating that their dominant language was English. All were right-handed as assessed by our internal handedness questionnaire and reported no left-handed members in their immediate family. Behavioral data were acquired for each subject prior to the fMRI sessions. Stimuli used during behavioral and fMRI sessions were comparable in terms of length, frequency, imageability, and other variables, which are known to influence picture-naming speed.

Functional MRI (fMRI) data were acquired with a General Electric 3.0 Tesla magnetic imager equipped with echo-planar imaging (EPI) from Advanced NMR. For each subject, a conventional sagittal scout scan was first obtained from which the functional images were prescribed. Using an EPI gradient echo sequence (TR = 3000 ms; TE = 45 ms; a 64×64 scan matrix with a 24 cm FOV) 108 images were obtained for each subject over 19 slices (4 mm thick/1 mm gap). According to the atlas of Taillarach and Tournoux (1988) the most inferior and superior slices approximately corresponded to $z = -24$ and $z = +65$, respectively. A set of coplanar high-resolution EPI structural images (TR = 4000 ms; TE = 65 ms; matrix size 128×128 ; FOV = 20 cm) were also collected at the same time to later allow for spatial normalization of each subject's data into a standard coordinate system.

Subjects participated in two scanning sessions each lasting 5 min and 24 s. In both activation runs, 72 simple line drawings were presented. In the between-language switching condition, the stimuli were chosen from the Snodgrass and Vanderwert (1980) and the Pictures Please catalog (Abbate, 1984). In the within-

TABLE 1
Sample Stimuli and Conditions for the Between-Language Condition

				
Picture	"Cue" response	"Cue" response	"Cue" response	"Cue" response
Condition				
Blocked English	"Say" book	"Say" bread	"Say" cake	"Say" bed
Blocked Spanish	"Diga" libro	"Diga" pan	"Diga" pastel	"Diga" cama
Mixed	"Say" book	"Diga" pan	"Say" cake	"Diga" cama

language switching condition, a set of 72 black line drawn test pictures of common actions were selected from a group of 120 action pictures. An example of four stimuli used in the between and within-language condition can be seen in Tables 1 and 2.

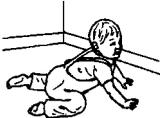
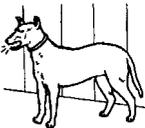
In each activation block, 18 pictures were presented at the rate of one every 2 s. Participants were shown a cue, "say" or "diga" for the between language condition and "to" or "the" for the within-language condition, visually for 200 ms. Participants were instructed to covertly name the picture in the language of the cue (say = English, diga = Spanish) in the between-language condition or to name the picture as an action (to) or as an object (the). The cue was followed immediately by the picture which was presented for 800 ms. There was 1000 ms delay prior to the next stimulus presentation. In the mixed condition, the cue switched on every picture for both the between-language (say, diga, say, diga) and the within-language (to, the, to the) conditions. The order of presentation of the four blocks (two mixed, one Spanish and one English in the between-language switching condition; two mixed, one action and one object in the within-language switching condition) was counterbalanced across subjects. The activation blocks alternated with five rest periods of 36 sec each, during which the subjects were instructed to

rest. An example of each of these runs can be seen in Figs. 1 and 2.

To correct for head motion, the functional images for each subject were realigned with Statistical Parametric Mapping Program, 1996 (SPM '96) (Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK) (Friston, 1995), using a six-parameter rigid body transformation model. The realigned data were then spatially transformed into Talairach space (Talairach *et al.*, 1993) as defined by the standard brain of the Montreal Neurological Institute (Canada) (provided in SPM '96). This spatial normalization involved a 12-parameter affine (linear) and quadratic (nonlinear) three-dimensional transformations, followed by a two-dimensional piece-wise nonlinear matching using a set of smooth basis functions that allow for normalization at a finer anatomical scale (Friston, 1995). As a final preprocessing step, all images were smoothed using an 8-mm FWHM isotropic Gaussian kernel to increase the signal to noise ratio.

Comparisons were calculated using a corrected significance level (height threshold) of $P < 0.05$ and an additional corrected spatial extent threshold of $P < 0.05$ (SPM '96 Friston, 1995). In the between-language condition, these contrasts included Spanish vs rest and English vs rest. In the within-language condition,

TABLE 2
Sample Stimuli and Conditions for the Within-Language Condition

				
Picture	"Cue" response	"Cue" response	"Cue" response	"Cue" response
Condition				
Blocked Action	"To" crawl	"To" blow	"To" eat	"To" bark
Blocked Object	"The" baby	"The" candle	"The" hotdog	"The" dog
Mixed	"To" crawl	"The" candle	"To" eat	"The" dog

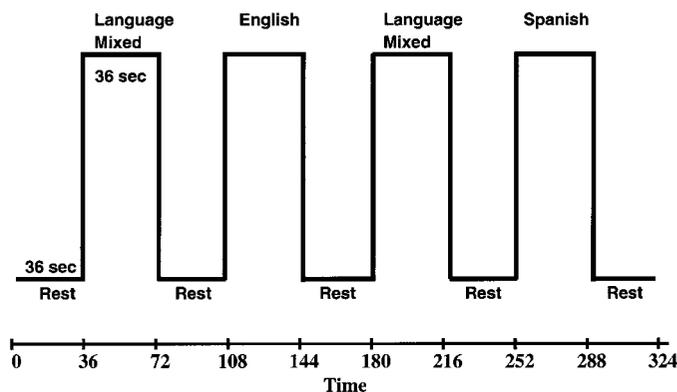


FIG. 1. Example of the paradigm used in the between-language switching condition.

these contrasts included object naming vs rest, action naming vs rest, blocked naming vs rest, and mixed naming vs rest. In addition, direct comparisons between two activation conditions (i.e., Spanish vs English or action vs object, etc.), were performed at a significance level of $P < 0.05$, using the initial comparisons (i.e., Spanish vs rest, action vs rest) as masks. Comparisons between mixed vs blocked conditions were additionally performed in the dorsolateral prefrontal cortex (both right and left hemisphere) at a significance level of $P < 0.05$ without correction for spatial extent. Finally, when null results were found we lowered the threshold substantially ($P < 0.2$ for height without correction for spatial extent) in order to verify whether differences were present with increased sensitivity. Statistically significant areas were superimposed on individual brain anatomy in Talairach space using SPM routines.

RESULTS

Behavioral

Between-language switching condition. Behavioral data for this condition were placed into a 2 (lan-

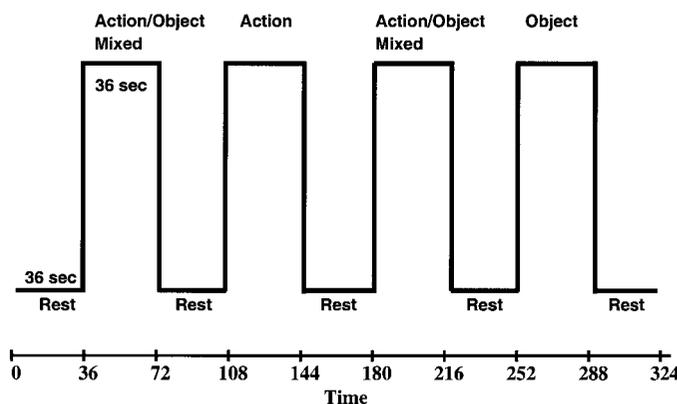


FIG. 2. Example of the paradigm used in the within-language switching condition.

guage) \times 2 (blocked/mixed) condition within-subjects ANOVA. Results revealed a main effect of language in terms of percentage correct, $F(1,5) = 23.58$, $P < 0.008$, and reaction time, $F(1,5) = 33.80$, $P < 0.004$, such that subjects were faster and more accurate in English than in Spanish. The effect of mixed vs blocked did not reach significance but was in the expected direction.

Within-language switching condition. Behavioral results for this condition were placed into a 2 (action/object) \times 2 (blocked/mixed) condition within-subjects ANOVA. None of the effects reached significance for our behavioral data. The behavioral results from both conditions can be seen in Table 3.

Neuroimaging

Between-language switching. The activation vs rest comparisons for this run revealed activation in the frontal cortex which included the dorsolateral prefrontal cortex (BA 46 and 9), Broca's area (BA 44 and 45) in the left hemisphere in all of these comparisons. The location (in Talairach coordinates) and peak height of all clusters of activation exceeding a corrected significance level of $P < 0.05$ (for both magnitude and spatial extent) for these statistical comparison can be seen in Table 4.

We then performed direct comparisons between the mixed and blocked activation conditions using the respective activation vs rest comparisons (mixed vs rest and blocked vs rest) as a mask. Results revealed significant activation in the left inferior frontal gyrus (area 44/45) when comparing the blocked-language condition to the mixed-language condition (see Table 2), $P < 0.05$ uncorrected. Finally, based on the Hernandez *et al.* study (2000) we established a region of interest in the left and right dorsolateral prefrontal cortex and used a height threshold of $P < 0.05$ without correcting for spatial extent. In this comparison, there

TABLE 3

Mean Reaction Times and Accuracy for the Between- and Within-Language Switching Condition

Response	<i>n</i>	Condition	RT (ms)	Percentage correct
Between-language switching				
English	6	Blocked	805	89%
		Mixed	907	84%
Spanish	6	Blocked	1012	69%
		Mixed	965	69%
Within-language switching				
Action	16	Blocked	950	86%
		Mixed	968	73%
Object	16	Blocked	1031	87%
		Mixed	961	85%

TABLE 4
Foci of Activation for the Between-Language Switching Condition

Comparison			Mixed-language condition vs rest				Blocked-language condition vs rest			
			<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>	<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>
Region (Brodmann area)										
Inferior frontal gyrus	(BA 44)	L	-52	12	14	7.41	-56	8	14	6.00
	(BA 44)	L	-50	4	22	6.89	-50	4	22	6.45
	(BA 6)	L	-36	2	42	4.35	-38	-2	42	4.93

Note. L and R refers to the left and right cerebral hemispheres, respectively, while *x*, *y*, and *z* reflect positions in Talairach coordinate space corresponding to the left-right, anterior-posterior, and superior-inferior dimensions, respectively. *Z* refers to the highest *Z* score within a region.

was significantly more activation in the right dorsolateral prefrontal cortex for the mixed-language condition relative to the blocked-language condition (area 46/9). We also explored differences across the two languages by looking at direct comparisons with a lower threshold of $P < 0.2$ for height and uncorrected for spatial extent. This resulted in no significant areas of activation. The results from the comparisons between mixed and blocked conditions can be seen in Table 5.

Within-language switching. Statistical comparisons for this run were conducted in the same manner as the between-language run. First, the comparison of picture naming to rest was performed across all conditions (mixed vs rest, blocked vs rest, action naming vs rest, and object naming vs rest). Statistical comparisons corrected for height and spatial extent at $P < 0.05$, revealed activation in the frontal cortex, which included the dorsolateral prefrontal cortex (BA 46 and 9) and Broca's area (BA 44 and 45) in the mixed vs rest comparison only. Additionally analyses of the blocked vs rest comparison did reveal differences in these same areas but only at $P < 0.01$ (uncorrected) for spatial extent. Furthermore, none of the comparisons between action and object naming or between mixed and blocked conditions yielded significant results (with the corresponding activation vs rest comparisons as masks). To further insure these results were not due to a lack of sensitivity we lowered the threshold to $P < 0.2$ for height and uncorrected for spatial extent for our direct comparison using activation vs rest as a mask.

The lowering of the threshold did not reveal areas of increased activation. Hence, we are confident that if any differences do exist they are well below the thresholds in which we observed differences in the between-language switching condition. The results for these conditions can be seen in Table 6. In addition, statistical parametric maps for the activation vs rest conditions for both the within-and between-language switching condition can be seen in Fig. 3.

DISCUSSION

The current study was designed as a replication and extension of a previous study at a higher field strength using SPM as the statistical tool. As in previous studies, we found that naming objects (as compared to rest) led to activation in the frontal cortex, which extended from the dorsolateral prefrontal cortex to the premotor area in the left hemisphere. This pattern of activation was similar to the one obtained in the within-language switching condition. Like previous studies with highly fluent bilinguals there was no difference between areas found to be active for each language. This was true despite the fact that naming was faster and more accurate in English than in Spanish. A similar pattern was also observed in the within-language switching condition where no difference was observed between object naming and action naming (within a language).

The most central aspect of the study revolved around the comparison between the mixed and blocked activa-

TABLE 5
Foci of Activation in the Direct Comparison Between Mixed and Blocked Conditions (Between-Language Condition)

Comparison			Mixed-language vs blocked-language condition				Blocked-language vs mixed-language condition			
			<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>	<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>
Region (Brodmann area)										
Inferior frontal gyrus	(BA 44/45)	L					-48	18	16	3.98
	(BA 46)	R	44	32	18	3.15				

TABLE 6
Regions of Significant Activation in the Within-Language Switching Condition

Comparison	Mixed-language condition vs rest				Blocked-language condition vs rest					
	<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>	<i>x</i>	<i>y</i>	<i>z</i>	<i>Z</i>		
Region (Brodmann area)										
Inferior frontal gyrus	(BA 44)	L	-40	6	22	6.87	-36	6	22	3.74*
	(BA 44/6)	L	-56	6	16	6.77	-56	6	14	3.55*
	(BA 6)	L	-34	0	44	5.25				
Middle frontal gyrus	(BA 46)	L					-46	16	24	3.43*

* These comparisons were corrected for intensity ($P < 0.05$) but not for spatial extent ($P < 0.01$ uncorrected).

tion conditions. These comparisons were only significant in the between-language condition. As we hypothesized there was an increased intensity of activation in the right dorsolateral prefrontal cortex for switching relative to no switching but only in the between-language condition. Furthermore, there was an increased area of activation in the left inferior frontal gyrus for the blocked condition relative to the mixed condition. This suggests that switching between languages in picture naming involves increased executive function as opposed to increased phonological recoding or motor planning.

The current study carries implications for the ability to switch between-languages. For example, several studies in our laboratory have explored the nature of switching costs across the lifespan. Studies using a cued picture naming task similar to the one used in the current study have revealed that the magnitude of between-language switching costs are largest in young

children, decline until age 18, remain stable until age 50, and increase again after age 65 (Hernandez and Kohnert, 1999; Kohnert *et al.*, 1999). This pattern coincides with the "rise and fall" of the frontal lobes and its cognitive functions such as executive function and working memory (Espy *et al.*, 1999; Stuss *et al.*, 1996; Welsh and Pennington, 1988; Welsh *et al.*, 1991). This provides converging evidence for the involvement of the frontal lobes in the between-language switching task employed in the current study. Hence, it appears that the frontal lobe, specifically the dorsolateral prefrontal cortex, does play a role in the ability to switch between two languages in the cued picture naming task we have used.

As noted in the introduction, Price *et al.* (1999) did not find any evidence of dorsolateral prefrontal activation in language switching or in translation. This suggests that not all switching tasks involve increased

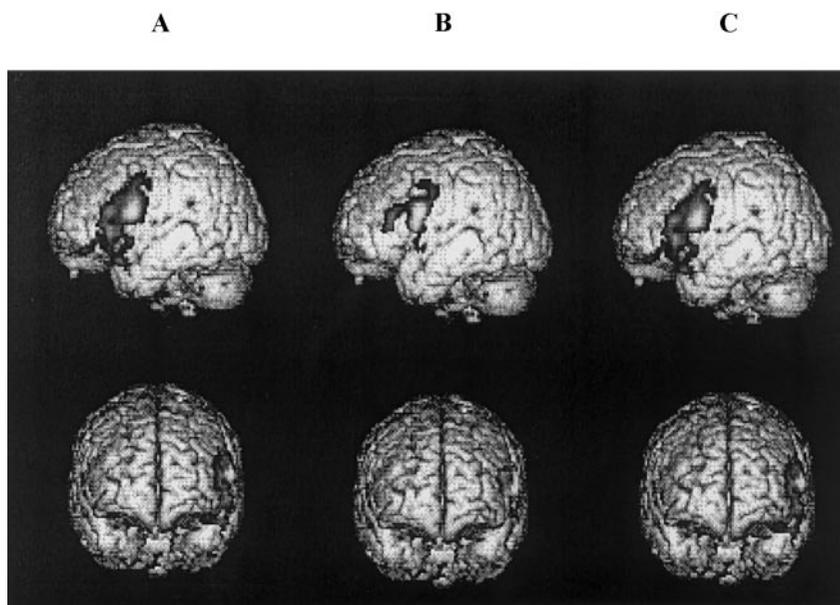


FIG. 3. Brain activity observed in the between-language and within-language switching condition. Statistical parametric maps of the t statistics (transformed to the unit normal distribution) for the mixed language condition vs rest (A), the blocked language condition vs rest (B), and the mixed action/object condition vs rest condition (C) rendered onto a standard brain, thresholded at $P < 0.05$ (corrected) for height and spatial extent.

executive function (or at least not enough to lead to significant increases in activation of the dorsolateral prefrontal cortex). Studies in our laboratory have explored switching costs in reaction time for a wide variety of tasks. These include within-language switching costs between naming actions and objects (similar to the task used in the current study) and between languages using auditory word repetition, picture naming and translation. In addition, we have found switching costs using a nonverbal perceptual switching task. However, not all of these tasks show the *u*-shaped increase, decrease, and increase in the magnitude of switching costs across the lifespan. For example, switching languages using translation and auditory word repetition do not show the same increase in age-related switching costs that have been observed using the cued picture naming paradigm.

The fact that not all types of switching are dependent on executive function (and hence on the dorsolateral prefrontal cortex) may help to elucidate the nature of activation in the within-language switching condition in the current study. One possibility is that the task used in the within-language condition in the current experiment might not have required the same amount of executive function as our between-language switching task. It is important to note that no differences in within-language switching were observed even when the threshold was lowered. This is consistent with the view that within-language switching does not result in increased executive function (at least not to the same extent). Future studies should explore more carefully different types of tasks in order to better understand when switching costs do and do not appear. In addition, it is important to establish which tasks are reliant on executive function and by consequence reveal activation in the dorsolateral prefrontal cortex when switching is required (for discussion of perceptual switching see Lumer *et al.*, 1998).

There is another manner in which the current study differed from the Price *et al.* (1999) study. We found that the blocked condition shows additional activation not observed in the mixed condition. The area of activation observed was in the inferior frontal gyrus (areas 44 and 45). Of particular interest is the fact that Price *et al.* (1999) observed increases in activation in this area when comparing mixed with blocked language processing. That is the opposite pattern of findings in the current study. How can we reconcile these differences? We suggest that these differences in activation pattern have to do both with the task and timing parameters employed in each study. Price *et al.* (1999) used translation and reading at rate of one stimulus every 3 s. We used picture naming at the rate of one stimulus every two seconds. The use of picture naming, a task which we suspect involves greater executive function when switching between languages, at a faster rate of presentation most likely lead to increased

interference in the mixed design. Furthermore, the faster rate involved additional processing load in the blocked condition, as evidence by the increased activation of Broca's area in this condition. It is our hypothesis that the task utilized by Price *et al.* (1999) and the current task lie on a continuum of processing difficulty. Hence, their switching condition may be equivalent to our blocked condition in terms of difficulty. This suggests that manipulation of task parameters which increase cross-language interference in translation and reading tasks could potentially lead to concomitant increases in activation of the dorsolateral prefrontal cortex. However, additional studies are needed to better understand the nature of language switching across translation, picture naming and other tasks.

Another dimension on which our study differs from Price *et al.*'s (1999) is the use of a cue to indicate the language of response. It is possible that the cue might have required that a person maintain the cue in memory and that this leads to the increased activation in the dorsolateral prefrontal cortex. Previous studies in our laboratory have found that switching costs were largest when switching on every trial compared to switching on random trials. This suggests that these costs are associated with the act of switching and not with the maintenance of the cue in memory (Hernandez and Kohnert, 1999).

Finally, the current study relied on comparisons between high frequency switching and no switching. Some authors have suggested that differences between a pure (i.e., blocked) condition and an alternating condition (i.e., mixed) could be due to maintaining two sets in mind or to reconfiguring between the two sets (Rogers and Monsell, 1995). One way to solve these issues is to use a design whereby one looks at switch trials and repeat (or no-switch) trials within the same run. A recent study by Dove *et al.* (2000) found that switch trials compared to no-switch trials revealed increased activation bilaterally in the prefrontal cortex, the anterior cingulate gyrus, the supplementary motor area, and in the left intraparietal sulcus. However, these areas also showed activity during no-switch trials. Dove *et al.* (2000) concluded that switching involves an increase (rather than additional recruitment) in areas that are active during no-switch trials. Another approach to this issue is to use a parametric approach in which switching is increased in a graded fashion. For example, Garavan *et al.* (2000) have found that parametric manipulation of task switching difficulty results in activation in areas that are adjacent to those which do not increase with difficulty.

One limitation of the current study is the comparison between mixed and blocked language processing. The differences in activation that we have observed could be due to the necessity of keeping two languages in mind or to the need to reconfigure between languages on each trial. These two effects could be the cause of

the observed increase in activation. Future studies using a parametric approach and a switch/no-switch design could help to further disentangle whether our effects (or which effects) are due to maintaining two languages in mind and which are due to having to switch between two languages.

The second issue that was addressed by the current study revolved around the separate vs. shared neural representation of different lexical classes. We found no evidence that processing of different lexical classes leads to different areas of activation. This is important because our study used stimuli which could have both an action and an object response. Hence, it is consistent with the notion that action and object naming involve highly overlapping neural systems. However, we interpret this nonfinding with caution. Like any study with null results it is possible that we simply did not have the sensitivity to detect the subtle differences between the naming of actions and objects. However, even when lowering the threshold we found no difference in activation across tasks. There are many reasons we could have failed to observe these effects. Future studies should investigate this more clearly by looking at action and object naming in a variety of conditions and for a variety of stimuli. These studies will help to further understand under which conditions the naming of actions and objects differ.

There is another manner in which the current study leaves open questions about the neurological underpinnings of bilingualism. Our study used picture naming, a task which is thought to tap into single word production. Hence, it is difficult to establish that this particular task is representative of the entire range of bilingual language processing. There are other tasks that could be used both at the single word level and at the sentence and discourse level. One area that has been largely understudied is the nature of syntactic differences in bilinguals. For example, there is evidence in the event-related potential literature that syntactic processing may be more sensitive to age of acquisition than semantic processing (Weber-Fox and Neville, 1996). Future studies could compare differences in syntactic performance across languages, levels of fluency, and age of acquisition.

The issue of syntactic differences brings up another important point when considering the neural representation of language in bilinguals. How do we know where these differences may occur? So far we have considered issues which apply to bilinguals regardless of the language spoken. However, some computational processes may differ across languages. For example, Paulesu *et al.* (2000) examined the differences in the neural activation of reading in monolingual English and Italian speakers. The results revealed a large overlap in the areas that were active for each language. In addition, areas of increased activation that were specific to each language were observed in the left inferior

frontal lobe and inferior temporal lobe (English) and the left superior temporal lobe (Italian). These areas are hypothesized to reflect the different computational demands posed by reading in different languages. Similarly, differences across languages have been found when comparing tone perception in Chinese, English, and Thai (Gandour *et al.*, 2000). A similar argument could also be used for the processing of syntax. For example, there are syntactic computations that exist in Spanish and not in English (gender markings on nouns, conjugations of verbs, etc). One might posit that similar dissociations across languages will occur in situations where languages differ in their syntactic computations. Any study with bilinguals must consider carefully the languages used and the computational properties of those languages.

As mentioned earlier, studies have found evidence that fluency plays a strong role in whether differences in activation are observed in late bilinguals (Perani *et al.*, 1998). Furthermore, other studies have found that practice can reduce activation differences. For example, Raichle *et al.* (1994) asked participants to generate verbs to a noun or simply repeat a noun. Generation compared to repetition resulted in increases in activation in the anterior cingulate gyrus, the left prefrontal cortex, left posterior temporal cortex, and the right cerebellar cortex. However, the areas of increased activity for the generation task were reduced almost completely with 15 min of practice. Hence, task difficulty can increase the amount of neural activation. In a similar vein, fluency is a form of practice. The larger the fluency differences across languages in a bilingual the larger the differences in activation. By using bilinguals who were highly fluent in both languages the current study overcomes this confound of differential task (i.e., language processing) difficulty.

In summary, our results qualify a number of observations made in the literature. First, Broca's area was more active during picture naming in one language whereas the dorsolateral prefrontal cortex is active during language switching. Hence, switching between languages involves aspects of central executive function. Second, we failed to observe differences in activation for each language in early bilinguals. This is consistent with the view that bilinguals who are highly fluent in both languages show very few differences in neural activation when naming pictures. These findings are consistent with the view that switching between languages results in an increase in executive function.

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